Wave Height Transformation on the WCSP-DS Zigzag Model with and Without Wave Focused Wall

Wa Ode Zulia Prihatini[1*], Muhammad Arsyad Thaha[2], Mukhsan Putra Hatta[3], Chairul Paotonan[4]

[1]Doctoral Student, Department of Civil Engineering, Hasanuddin University, Indonesia

[2]Professor, Department of Civil Engineering, Hasanuddin University, Indonesia

[3]Associate Professor, Department of Civil Engineering, Hasanuddin University, Indonesia

[4]Associate Professor, Department of Marine Engineering, Hasanuddin University, Indonesia

*Corresponding Author

Abstract.

This study aims to examine and obtain the magnitude of the influence of several factors on the magnitude of the increase in height wave deformation (Hdf). The research was conducted at the Coastal Engineering Research Laboratory, Faculty of Engineering, Hasanuddin University, Indonesia. Experimental research on 3D physical models in a 10m x 15m wave pool with a depth of 1.0m. Two types of WCSP-DS models with and without wave energy centering walls (WFW), at the geometric scale of 1:20, were simulated with 3 kinds of wave heights and periods (H and T), 5 kinds of freeboard heights (Fb) on 3 kinds positions of elevation of the water level in relation to the vertical wall of the model (d/z). The results showed that the model with and without a wave-focused wall (WFW) experienced a significant increase in wave height from P1 to P11, the installation of the wave-focused wall (WFW) significantly increased the height of the waves entering the models WCSP- DS. The position of elevation of the water level in relation to the vertical wall of the model (d/z) that has the greatest influence on the increase in wave height is d/z = 1.143. The freeboard height (Fb) has no significant effect on the deformation height wave that occurs. The wave from point P1 to P11 becomes higher in P11, this indicates a superposition of the incident wave and the reflected wave which produces a standing wave.

Keywords: Energy converter., Freeboard., Relative depth., Wave deformation

1. Introduction

Indonesia is one of the countries with the largest maritime area. About two-thirds of Indonesian territory is maritime. Indonesia has the second longest beach in the world after Canada. This is an advantage for Indonesia in terms of the potential availability of marine energy. Ocean energy generated by the movement and temperature difference of the marine (ocean) layer is a new source of renewable energy in marine waters in the form of tidal energy, wave energy, current energy ocean waves, and marine layer temperature difference energy. Unfortunately, the technology of using marine energy in Indonesia has not yet found a financially feasible concept to implement. Further research is still needed taking into account the existing environmental conditions.

The energy needs of today and tomorrow will greatly increase with the growth of the world population and industry which is quite high. The reserves of non-renewable energy sources that have been mostly used are now starting to run out and will run out in the next few years. In Indonesia, energy consumption is still dominated by fossil fuels (oil, natural gas, and coal) while new and renewable energies (EBT) are still alternative. Dependence on fossil fuels poses at least three serious threats, namely: Depletion of existing oil reserves (assuming no new oil wells are discovered); price increase/instability due to higher demand rate of oil production, and greenhouse gas pollution from burning fossil fuels. (Lestari, 2021)

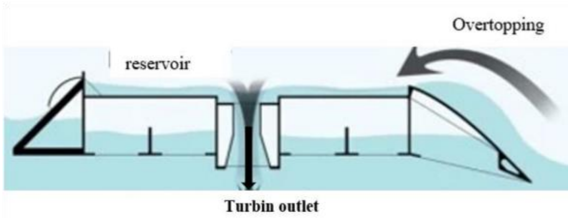
It is time to develop new renewable energy sources and one of the renewable energy sources is sea waves. Wave energy is a function of wave height and wave period. These two parameters, therefore, become very important. The height of the waves varies from place to place. The characteristics of wave energy are very suitable to meet the energy needs of port cities and remote islands in Indonesia. Sea waves are one of the hydrodynamic activities that occur in the sea and beaches due to the process of energy transfer from the wind to the generating area. The waves that travel from deep to shallow water on the coast have great energy and are sometimes so large that they are known to have great destructive power. In order to protect coastal areas and some port areas, it is sometimes necessary to build expensive breakwaters to destroy the energy needed to protect these areas. This paradigm no longer seems suitable for current and future conditions. It is necessary to develop a multi-purpose coastal protection building in addition to protecting the coast, it is also a wave power station.Research and exploration efforts on the use of wave energy have been carried out in many parts of the world, especially in the areas of the Pacific Ocean, Atlantic Ocean, and the Indian Ocean. , with the exception of Indonesian waters bordering the Indian Ocean which have not yet been developed. While based on information that along the south coast of Java to Nusa Tenggara there are places that have a sufficiently large wave energy potential ranging from 10 to 20 kW per wavemeter. Several studies have concluded that wave energy at some locations in Indonesia can reach 70 kW/m. The west coast of the southern part of the island of Sumatra and the south coast of the western part of the island of Java also have the potential to have sea wave energy of around 40 kW/m. Several issues hinder the development of wave power plants, including the instability of the electrical current generated (intermittent) so that it requires adequate technology and infrastructure to achieve stability. Another obstacle is that the investment cost to build a wave power plant is quite large, so the selling price of electricity becomes expensive and cannot compete with onshore power plants (Lestari, 2021). Therefore, the wave energy conversion should not stand alone with one function, it is necessary to think of multiple functions to reduce the investment cost.

This research is part of the research on the development of the Overtopping type WEC or Overtopping Wave Energy Converter (OWEC) concept which bears the name of Zig-Zag Model Wave Catcher Shore Protection (WCSP-DS). The WCSP-DS Zig-Zag model is the development of the OWEC breakwater research series studied by (Thaha et al, 2013-2020) at Coastal Engineering Research Center, Faculty of Engineering, Hasanuddin University, Indonesia. The efforts in this long research are aimed at finding solutions to the above two problems. The instability of the electric current produced can be overcome in the OWEC type because what is used is the potential energy of the waves. At the same time, the problem of financial insufficiency can be overcome by developing multi-benefits. One of the important aspects studied is the engineering to create a wave transformation that produces maximum wave height in front of the structure. The maximum wave height will produce a large overflow discharge and ultimately increase the wave energy that can be captured and used to spin the turbine.

The height of this breaking wave is determined by the height of the waves reaching the building that propagate from the deep sea. This study aims to examine and obtain the magnitude of the influence of several factors on the magnitude of the increase in deformation wave height (Hdf), including the 90° zig-zag placement shape, installation of a wall to concentrate the energy of the waves in conditions where there is an influence of the shoaling coefficient.

There are 4 known concepts of wave energy conversion, namely wave activated body, point absorber, oscillating water column, and overtopping. (Lopez in Dwipuspita et al., 2020) that the most popular and developed WEC technology is the point absorber type, while the unpopular and underdeveloped WEC technology is based on the overtopping concept. The concept used in the OWEC type converter is to accommodate the overtopping water in the reservoir, where the reservoir at the top of the converter with an elevation above sea level, potential energy is converted into mechanical energy by a turbine. The concept of an overtopping wave energy converter is shown in Fig.1

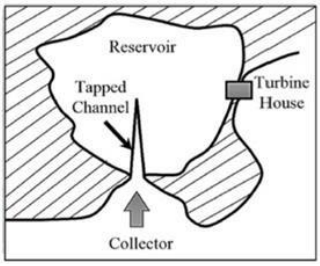
Figure 1: One of the concepts of WEC Overtopping (OWEC) technology



Source: (Waters R, 2008)

The first invention with the concept of overtopping was Tapered Chanel wave technology or commonly known as TAPCHAN. This type of overtopping WEC sink was first developed in Norway in 1980. The concept used in TAPCHAN is similar to traditional hydroelectric. power, where the ocean waves are concentrated up into the reservoir through an overtopping mechanism and from the reservoir which is located above sea level are released back to the sea via turbine housing, as shown in the illustration in Fig. 2.

Figure 2: Tapered Chanel (TAPCHAN)



Source: (Dwipuspita, 2020)

Airy wave theory is derived from Laplace's equation for irrotational flow with boundary conditions on the seafloor and on the water surface. The relationship between wave propagation velocity and wavelength and depth is:

$$C = \frac{gT}{2\pi} tanh \frac{2nd}{L} \quad (1)$$

And the relation of wavelength (L) in-depth function (d) is:

$$L = \frac{gT^2}{2\pi} tanh \frac{2nd}{L} \quad (2)$$

Analysis of wave transformation is often performed with the concept of equivalent deep waves, which is the height of deep-sea waves if the waves do not undergo refraction. The equivalent deep-sea wave height is given by the form:

$$H_o' = K'.Kr.H_o \quad (3)$$

Where, H_o': equivalent deep-sea wave height; H_o : deep-sea wave height; K': diffraction coefficient; Kr : coefficient of refraction.

The incoming wave that hits a building will be reflected in part or all of its energy. Knowledge of wave reflection is important in the design of coastal structures. In vertical buildings, smooth and impermeable walls, the waves will be completely reflected. The magnitude of a building's ability to reflect waves is given by the reflection coefficient (Kr), which is the ratio between the reflection wave height Hr and the incident wave height Hi:

$$Kr = \frac{Hr}{Hi} \quad (4)$$

Another wave deformation is the change due to shoaling. Shoaling is also measured through the Shoaling Coefficient, which is the ratio between deep-sea wavelengths and beach wavelengths.

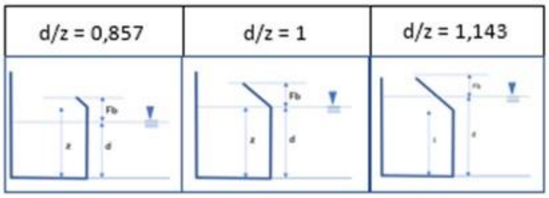
$$Ks = \sqrt{\frac{n_0 L_0}{nL}} \quad (5)$$

Where, n_0 = the depth factor of deep-sea waters which is 0.5, and the value of n moves to 1 in shallow seas.

2. Methods

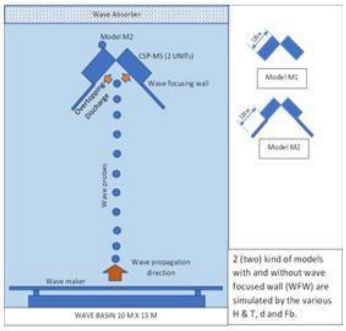
The research was conducted at the Coastal Engineering Laboratory, Faculty of Engineering, Hasanuddin University, Indonesia. Experimental research on 3D physical models in a 10 m x 15 m wave basin with a depth of 1.0m. Two types of WCSP-DS models with and without wave focusing wall (WFW), at the geometric scale of 1:20, were simulated with 3 kinds of wave heights and periods (H and T), 5 kinds of freeboard heights (Fb) at 3 positions of water level elevation relative to the vertical wall of the structure (d/z = 0.857; d/z = 1 and d/z = 1.143) as shown in Fig. 3.

Figure 3. Profile of 3 types of water level elevation relative to the vertical wall height of the structure.



Source: (Author, 2021)

Figure 4. The layout of 3D physical modeling.



Source: (Author, 2021)

The positions of probes P1 to P11 are ordered from the wave generator to the WCSP-DS model. Once the model has been manufactured and placed in the wave pool according to the plan of Fig. 4 the wave generator device is adjusted according to the simulation plan, then the calibration of the generator and the wave height measurement probes is performed, totaling 11 pieces. The next step is the simulation and acquisition of wave height data recorded in all the probes. Thus, the procedure is repeated with other variants.

3. Results and Discussion

The water level fluctuation record data from the simulation results were then converted to wave height (H) on all probes (P1 – P11). Tab. 1 presents a simulation run of 30 turns for the model without and with WFW.

Table 1: Wave height data for rotation d/z=1.143 and Fb = 0.25 m which are simulated for 3 different periods and wave amplitudes.

Model	Runn	Depth	Heigth of vert. wall	Freeboard	Periode	Deep sea length wave	Wave length	Amplitude	Running time	Wave heigth (m)										
	code	d (m)	z (m)	Fb (m)	T (s)	Lo (m)	L (m)	a (cm)	second	P 1	P 2	P 3	P 4	P 5	P 6	P 7	P 8	P 9	P 10	P 11
Without Focussed Wall	A11	0.4	0.35	0.25	2.0	6.24000	3.88367	4	180	0.073	0.069	0.119	0.124	0.116	0.120	0.114	0.107	0.057	0.152	0.239
	A12	0.4	0.35	0.25	2.0	6.24000	3.88367	5	180	0.095	0.091	0.156	0.147	0.145	0.138	0.138	0.129	0.065	0.178	0.294
	A13	0.4	0.35	0.25	2.0	6.24000	3.88367	6	180	0.116	0.118	0.193	0.183	0.172	0.152	0.168	0.162	0.078	0.193	0.352
	A14	0.4	0.35	0.25	2.3	8.25240	4.55565	4	207	0.110	0.125	0.165	0.071	0.088	0.162	0.116	0.069	0.130	0.256	0.318
	A15	0.4	0.35	0.25	2.3	8.25240	4.55565	5	207	0.125	0.165	0.202	0.095	0.100	0.216	0.156	0.088	0.170	0.289	0.386
	A16	0.4	0.35	0.25	2.3	8.25240	4.55565	6	207	0.152	0.189	0.249	0.113	0.125	0.264	0.196	0.107	0.206	0.311	0.450
	A17	0.4	0.35	0.25	2.6	10.54560	5.21804	4	234	0.045	0.118	0.101	0.049	0.131	0.122	0.091	0.049	0.129	0.241	0.292

	A18	0.4	0.35	0.25	2.6	10.54560	5.21804	5	234	0.064	0.150	0.137	0.074	0.157	0.152	0.118	0.082	0.156	0.292	0.369
	A19	0.4	0.35	0.25	2.6	10.54560	5.21804	6	234	0.088	0.193	0.164	0.089	0.188	0.186	0.128	0.118	0.182	0.325	0.431

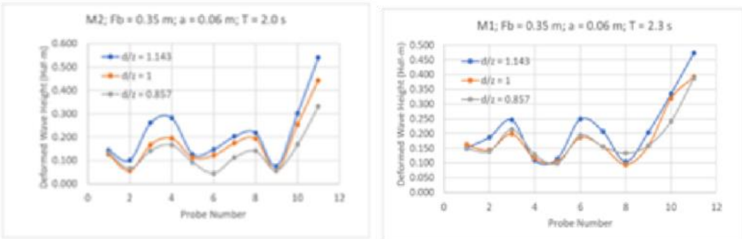
Source: (Author, 2021)

From all the data presented in Tab. 1, an analysis of the influence of several simulation parameters is carried out, including the relative depth of the model (d/z), the freeboard height (Fb), an increase from the wave height value until it is modeled with 2 simulation conditions with and without WFW.

3.1. Effect of relative model depth (d/z)

The first analysis to be carried out consists in comparing the effect of the vertical position of the water level on the wall of the WCSP-DS. There are 3 vertical positions studied for their influence, namely d/z = 1.143, i.e. the water level is on a 45° inclined wall, d/z = 1, i.e. the water level is at the meets straight and sloping walls and d/z = 0.857, i.e. the water level is at the straight wall. Fig. 5 presents a comparison of the strain wave profiles for the 3 different water level positions in the model without and with WFW under conditions of freeboard height (Fb), amplitude (a) at both at wave period (T) = 2.0 s and at T = 2.3 s.

Figure 5. Comparison of deformation wave profiles that occur at 3 different elevation positions



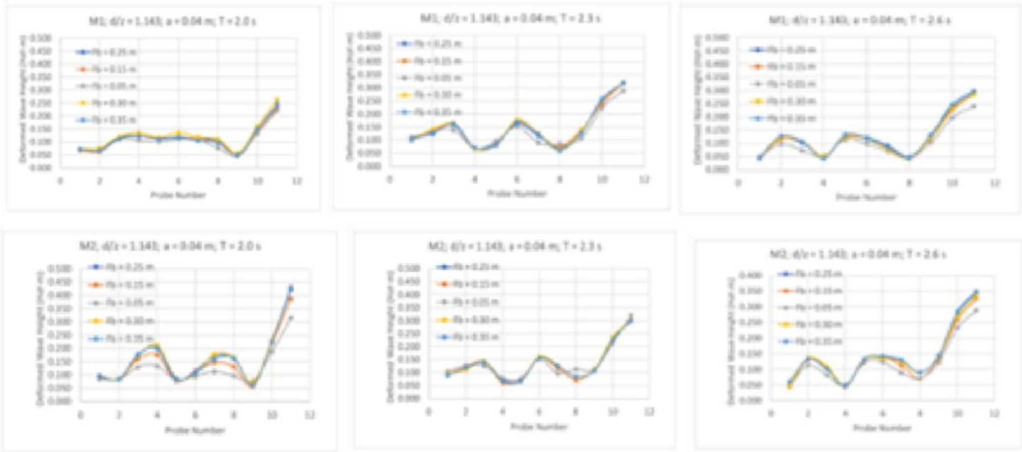
Source: (Author, 2021)

From Fig. 5 it can be seen that all the strain wave profile curves that occur in the M1 model or the model without WFW, as well as the M2 model or the model with WFW, experienced a very significant increase in the height of the waves from Probe 1 to Probe 11. From the three curves of the two models, it can be seen that the relative elevation position of the face (d/z) which has the greatest influence on the increase in the wave height is d/z = 1.143. Thus, further studies will focus on the d/z value.

3.2. Freeboard High Influence (Fb)

One of the important variables in the OWEC study is the freeboard depth (Fb). The freeboard height greatly influences the overflow discharge unit (q) that enters the tank and is also an important variable in determining the water level difference in the tank and the sea (h) which determines the amount of energy that can be generated. Fig. 6 presents an overview of the effect of Fb on the strain wave height (Hdf) in the 2 models tested.

Figure 6. Effect of Fb on the deformation wave height (Hdf) at M1 (top) & M2 (bottom) for T = 2 s; T = 2.3 s and T = 2.6 s.



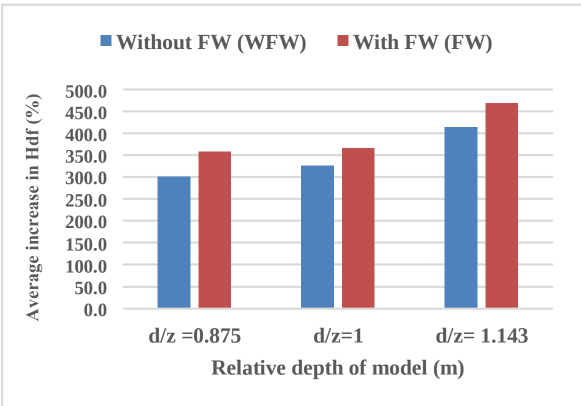
Source: (Author, 2021)

From the 6 graphs in Fig. 6 it is clear that in all experimental conditions, the freeboard height (Fb) has no significant effect on the magnitude of the deformation wave height that occurs. It is also seen that the effect of T is also not significant in the values of 2.0 s to 2.6 s. The wave height recorded along with the propagation from point P1 to point P11 fluctuates and ends up being very high at point P11. This indicates a superposition of the incident wave and the reflected wave which produces a clapotic wave. From the graphs M1 and M2 it is shown that the installation of WFW significantly increases the incoming wave height towards the WCSPDS model.

3.3. Magnitude of Wave Height Increase

Waves that propagate from deep sea to shallow sea on the coast will undergo wave height transformation. The higher the height of the waves, the greater the energy captured. Fig. 7 shows the percentage increase in wave height from point 1 in the open sea to point 11 ahead of the model.

Figure 7. Average increase in Hdf (%) for 3 kinds of relative depth (d/z) in models with & without WFW.



Source: (Author, 2021)

From Fig. 7 it is clear that the larger the d/z value of the studied , the greater the percentage increase in the strain wave height (Hdf). It is also clear the effect of adding WFW, where the increase in Hdf in WCSP-DS with WFW is greater than in WCSP-SD without WFW

4. Conclusion

From the results of the analysis carried out, it can be concluded that model with and without a wave-focused wall (WFW) experienced a significant increase in wave height from P1 to P11, the installation of the wave-focused wall (WFW) significantly increased the height of the waves entering the models WCSP- DS. The position of elevation of the water level in relation to the vertical wall of the model (d/z) that has the greatest influence on the increase in wave height is d/z = 1.143. The freeboard height (Fb) has no significant effect on the deformation height wave that occurs. The effect of the period (T) is also not significant in values from 2.0 s to 2.6 s. The wave from point P1 to P11 becomes higher in P11, this indicates a superposition of the incident wave and the reflected wave which produces a standing wave.

Acknowledgment

We to express our gratitude and our highest gratitude to all those who helped and supported our research so that we could complete this research, in particular to Prof. Dr. Ir. H. Muhammad Arsyad Thaha, MT as Dean of Faculty of Engineering, Hasanuddin University Makassar, Indonesia and Management of the Coastal Engineering Laboratory, Faculty of Engineering, Hasanuddin University, Makassar, Indonesia.

References

Dean, R.G. Dalrymple, R.A, (2000). *Water Wave Mechanics For Engineer and Scienties*, Singapore, World Scientific.

Diego Vicinanza, Ph.D.,Enrico Di Lauro, Ph.D.,Pasquale Contestabile, Ph.D., Corrado Gisonni, Ph.D., Javier L. Lara, Ph.D., and Inigo J. Losada, M.ASCE. (July, 2019). " Review of Innovative Harbor Breakwaters for Wave-Energy Conversion", *Journal of Waterway, Port, Coastal and Ocean Engineering*, DOI: 10.1061/(ASCE)WW.1943-5460.0000519.

M. A. Thaha, Nizam, R. Triatmadja and A. I. Dwipuspita. (2013). "Factors Affecting The Low Achievement of Utilization Efficiency of Wave Energy for Electric Power Plant with Tapered Channel Technology", *Proceedings of the 7th International Conference on Asian and Pacific Coasts (APAC),* Bali Indonesia, pp.896-902.

Muhammad Arsyad Thaha, Mukhsan P H, A. Subhan M and A.Ildha Dwipuspita. (2018). "Single Slope Shore Protection as a Wave Energy Catcher", *MATEC Web of Conferences*, 203, 01008, https://doi.org/10.1051/matecconf/201820301008.

Puspita, A Ildha. (2020). "Pengaruh Deformasi Gelombang terhadap Debit Overtopping Wave Energi Converter (OWEC)- Breakwater, Disertasi, Universitas Hasanuddin Makassar.

Thaha, A., Maricar, F., Aboe, A. and Dwipuspita, A. (2015). "The breakwater, from wave breaker to wave catcher", *Procedia Engineering Elsevier*, pp. 691- 698.

Vita Puji Lestari. (2021). "Ringkasan Permsalahan dan Tantangan Program Peningkatan Energi Baru dan Terbarukan dalam Bauran Energi Nasional". *Pusat Kajian AKN, Badan Keahlian DPR RI.* Jakarta.

Water, R. (2008). "Energy from Ocean Waves Full Scale Experimental Verification of a Wave Energy Converter", Digital Comprehensive Summaries of Uppsala Disertations from the Faculty of Science and Technology 580.130 pp.Uppsala. ISBN 978-91-554-7354-9